

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget: Paperwork Reduction Project (0704-0188), Washington, DC 20503.</p>			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	July 10, 1995	Final	1 Jun 91 - 31 Jul 95
4. TITLE AND SUBTITLE	5. FUNDING NUMBERS		
A book and series of monographs on ice physics			
6. AUTHOR(S)	7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		
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8. PERFORMING ORGANIZATION REPORT NUMBER		9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	
DAAL03-91-G-0164		U. S. Army Research Office P. O. Box 12211 Research Triangle Park, NC 27709-2211	
10. SPONSORING / MONITORING AGENCY REPORT NUMBER		11. SUPPLEMENTARY NOTES	
ARO 28599.4-G-S		<p>The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.</p>	
12a. DISTRIBUTION / AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
Approved for public release; distribution unlimited.		SUPERcedes AD-A 288319	
13. ABSTRACT (Maximum 200 words)			
<p>During the period June 1, 1991, through May 31, 1995 seven monographs on the physics of ice were written and printed:</p> <ol style="list-style-type: none"> 1. The Structure of Ordinary Ice. Part I: Ideal Structure of Ice. 2. Defects in Ice. Part I: Point defects. 3. Defects in Ice. Part II: Dislocations and Plane Defects. 4. Electrical properties of ice: <ul style="list-style-type: none"> Part I. Conductivity and Dielectric Permittivity of Ice. Part II. Advanced Topics and New Physical Phenomena. 5. The Surface of Ice. 6. Electromechanical Phenomena in Ice. 7. Optical Properties of Ice. <p>These monograph number 646 pages including 221 figures and 850 references. The lists of the monographs contents is in the Appendix. All the monographs of the series passed through intensive national and international review and were very well accepted by scientists and engineers working on ice. Eighth monograph entitled Photoelectric and Photoplastic Effects in Ice will be finished soon.</p>			
14. SUBJECT TERMS		15. NUMBER OF PAGES	
ice, ice physics, electrical properties of ice, mechanical properties of ice, structure of ice, ice defects		6	
16. PRICE CODE			
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

A BOOK AND SERIES OF MONOGRAPHS ON ICE PHYSICS

FINAL REPORT

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JULY 7, 1995

U. S. ARMY RESEARCH OFFICE

GRANT NUMBER DAAL03-91-G-0164

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STATEMENT OF THE PROBLEM

At present, many thousands of people around the world deal with ice, snow, and permafrost. They include basic and applied scientists, engineers, navigators, meteorologists and others. While just a small number of these people makes a contribution to basic Ice Physics, all of them use, more or less frequently, knowledge from it. Moreover, much successful applied research is based on fundamental science. This is just one reason for ice specialists to have an up-to-date textbook on Ice Physics on their desks.

Several times in the past this kind of book was produced. First it is necessary to mention Fletcher's book on "The Chemical Physics of Ice" [1]. Fletcher designed his book in a typical textbook format: it is reasonably brief and easy to understand. He touched on a few of the most important topics, but not all of them. The most complete and fundamental book of Ice Physics was written by Hobbs [2], in which he considered almost all aspects of the basic knowledge of ice known in 1972. Another work was subsequently written by John Glen in 1974 [3]. He wrote briefly and clearly and reviewed almost all subjects. This work (two monographs) was (and in some respects still is) a magnificent introduction to ice. Finally, Maeno wrote (in Japanese) a simple popular book [4] the purpose of which was to attract people's attention to the subject.

All of these are now out of date. During the past twenty years a significant amount of new experimental and theoretical work has appeared, to the extent that our views on Ice Physics have dramatically changed. New areas of research have opened up based upon recent discoveries. Intensive studies in physics, chemistry and the mechanics of ice have resulted in the formulation of physical laws using simpler and more direct ways; we have discovered that some of the physical models previously used were incorrect. So, we may now say that the Physics of Ice is a much better understood subject than it was twenty years ago. A list of particular achievements and discoveries in ice research was included in the first proposal.

These reasons explain the need for a new book on ice physics. The Principal Investigator was given a contract from ARO and US Army CRREL to produce such a book and began this work in June 1991.

SUMMARY OF THE MOST IMPORTANT RESULTS

During the period June 1, 1991, through May 31, 1995 seven monographs on the physics of ice were written and printed:

1. The Structure of Ordinary Ice. Part I: Ideal Structure of Ice.
2. Defects in Ice. Part I: Point defects.
3. Defects in Ice. Part II: Dislocations and Plane Defects.
4. Electrical properties of ice:
 - Part I. Conductivity and Dielectric Permittivity of Ice.
 - Part II. Advanced Topics and New Physical Phenomena.
5. The Surface of Ice.
6. Electromechanical Phenomena in Ice.
7. Optical Properties of Ice.

These monograph number 646 pages including 221 figures and 850 references. The lists of the monographs contents is in the Appendix. All the monographs of the series passed through intensive national and international review and were very well accepted by scientists and engineers working on ice. **Eighth monograph** entitled Photoelectric and Photoplastic Effects in Ice will be finished soon.

P. I. was simultaneously working on the united book on Ice Physics. This work is mostly accomplished and proposals were sent to four publishing houses : Oxford University Press, Cambridge University Press, Taylor & Francis and IOP. Oxford University Press and Taylor & Francis have finish the proposal evaluation are ready to sing a contract. Cambridge University Press and IOP will reply by October 1.

Below are the contents of these eight monograph:

1. THE STRUCTURE OF ORDINARY ICE Ih. PART I : IDEAL STRUCTURE OF ICE

1. INTRODUCTION
2. CHEMICAL CONTENT OF WATER AND ICE
3. WATER MOLECULES IN VAPOR, WATER AND ICE
4. NATURE AND PROPERTIES OF HYDROGEN BONDS,
5. PHASE DIAGRAM OF WATER AND PHASE TRANSITIONS
6. STRUCTURE OF ORDINARY ICE Ih. POSITIONS OF OXYGEN ATOMS
7. STRUCTURE OF ICE Ih. ARRANGEMENT OF PROTONS AND CONFIGURATIONAL ENTROPY OF ICE.
8. ELECTRONIC STRUCTURE OF ICE.

2. DEFECTS IN ICE. PART I. POINT DEFECTS

PREFACE
 INTRODUCTION
 NOMENCLATURE
 GENERAL CONSIDERATION OF POINT DEFECTS
 MOLECULAR DEFECT
 PROTONIC DEFECTS

STATISTICS OF PROTONIC POINT DEFECTS IN ICE
 ELECTRICAL PROPERTIES OF PROTONIC DEFECTS
 ACTIVATION VOLUME OF PROTONIC DEFECTS
 ATOMIC STRUCTURE OF PROTONIC DEFECTS

IMPURITIES
 ELECTRONIC DEFECTS
 FIGURES CAPTIONS
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3. DEFECTS IN ICE. PART II. DISLOCATIONS AND PLANE DEFECTS

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 1 INTRODUCTION
 2. DISLOCATIONS IN THE ICE STRUCTURE

- 2.1 Basal dislocations
- 2.2 Non-basal dislocations

 3. DIRECT OBSERVATION OF DISLOCATIONS

- 3.1 General
- 3.2 The X-ray topography technique
- 3.3 Grown -in dislocations
- 3.4 Dislocations associated with plastic deformation

 4. DISLOCATION MOBILITY

- 4.1 Experimental observations
- 4.2 The Peierls model for basal dislocations
- 4.3 Proton disorder

 5. THE ROLE OF DISLOCATIONS IN THE PLASTIC DEFORMATION OF SINGLE CRYSTALS

- 5.1 Pure crystals
- 5.2 Doped crystals and electrical effects

 6. STACKING FAULTS

- 6.1 The structure of stacking faults in ice
- 6.2 Observations of stacking faults

 7. GRAIN BOUNDARIES

7.1 Structure

7.2 Electrical properties of grain boundaries in doped ice

FIGURE CAPTIONS

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4. ELECTRICAL PROPERTIES OF ICE

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PART I CONDUCTIVITY AND DIELECTRIC PERMITTIVITY OF ICE

1. INTRODUCTION
2. THE NATURE OF ELECTRIC CHARGE CARRIERS IN ICE
3. JACCARD'S MODEL OF ELECTRICAL PROPERTIES OF ICE. INFINITE SIZE
 - 3.1 PROTONIC CHARGE CARRIERS
 - 3.2 ELECTRICAL PROPERTIES. ONE TYPE OF CHARGE CARRIER
 - 3.3 OTHER CHARGE CARRIER TRANSFERS AND THEIR EFFECTIVE CHARGES
 - 3.4 GENERAL CONSIDERATION OF JACCARD'S MODEL WITH FOUR KINDS OF CARRIERS
 - 3.5 ANALYSIS OF JACCARD'S RESULTS
4. ELECTRICAL PROPERTIES OF ICE OF FINITE SIZE
 - 4.1 LOW-FREQUENCY, LIMIT-SCREENING LENGTHS
 - 4.2 FREQUENCY DEPENDENCE OF DIELECTRIC PERMITTIVITY
5. CONCENTRATION OF CHARGE CARRIERS
 - 5.1 INTRINSIC CHARGE CARRIERS
 - 5.2 SUPERIONIC TRANSITION AND THE SUPERIONIC STATE OF ICE
 - 5.3 PROTONIC CHARGE CARRIERS INTRODUCED BY DOPING
6. EXPERIMENTAL TECHNIQUES FOR INVESTIGATION OF CONDUCTIVITY AND DIELECTRIC
 - 6.1 MEASURING CIRCUITS
 - 6.2 ELECTRODES
 - 6.3 SURFACE CONDUCTIVITY AND GUARD RINGS
 - 6.4 THE INFLUENCE OF INHOMOGENEITY ON THE FREQUENCY DEPENDENCE OF ICE
7. REVIEW OF EXPERIMENTAL RESULTS ON ICE CONDUCTIVITY AND DIELECTRIC PERMITTIVITY

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TABLE II

TABLE III

ELECTRICAL PROPERTIES OF ICE, PART II*ADVANCED TOPICS AND NEW PHYSICAL PHENOMENA*

9. RELAXATION TIMES OF ELECTRIC POLARIZATION AND ELECTRIC FIELDS IN ICE
10. RECOMBINATION INJECTION OF IONS INTO ICE
11. RECOMBINATION EXTRACTION OF CHARGE CARRIERS FROM ICE
12. PROTON INJECTION FROM PD ELECTRODES INTO ICE
13. FIELD ACTION TRANSISTOR MADE OF ICE
14. "CROSSOVER" IN THE DIELECTRIC PERMITTIVITY OF ICE
15. THERMALLY STIMULATED DEPOLARIZATION

CONCLUSION

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5. ICE SURFACE

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PART I. EXPERIMENTAL RESULTS ON THE STRUCTURE AND PROPERTIES OF ICE SURFACE

X-ray diffraction

Proton Channeling

Optical Ellipsometry

Nuclear Magnetic Resonance (NMR)

Electrical conductivity of ice surface

Surface Charge and Surface Potential

Surface electrochemical potential

Photoemission of electrons from the ice surface

Surface optical absorption in infrared region

Regelation (refreezing), sintering and adhesion

Absorption of gasses on the ice surface

Surface Energy

Summary of main experimental results

The existence of a special layer

The thickness of the layer and the domain of its existence

Molecular structure of the layer

Physical properties of the layer as compared with water and ice

PART II. THEORETICAL MODELS OF ICE SURFACE

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6. ELECTROMECHANICAL PHENOMENA IN ICE

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ELECTRICAL PHENOMENA IN ICE FRICTION

The structure and electrical properties of ice surface

Early works, asymmetric rubbing

Frictional electrification

Effect of electric fields on ice friction

ELECTRO ELASTIC EFFECTS

Is ice piezoelectric?

Phonon induced polarization of ice

Polarization induced by non uniform strain

Other pseudo piezoelectric effects

ELECTROMAGNETIC PHENOMENA IN ICE FRACTURE

Electromagnetic emission from cracks in ice

Theory

Laboratory experiments

Field experiments

PHENOMENA ASSOCIATED WITH MOTION OF CHARGED DISLOCATIONS

Dislocation currents in ice

Action of electric field on plastic deformation

Motion of dislocations in electric fields

Effect of static electric field on ice creep

Action of plastic deformation on electrical properties of ice

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7. OPTICAL PROPERTIES OF ICE

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ANISOTROPY AND BIREFRINGENCE OF ICE IH

ABSORPTION AND REFLECTION OF ULTRAVIOLET LIGHT

ABSORPTION AND REFLECTION OF INFRARED LIGHT.

RAYLEIGH SCATTERING OF ICE

RAMAN SCATTERING

PHOTOLUMINESCENCE

LUMINESCENCE UNDER ACTION OF HIGH ENERGY PARTICLES

THERMOLUMINESCENCE

TRIBOLUMINESCENCE

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FIGURES

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8. PHOTOELECTRIC AND PHOTOPLASTIC EFFECTS IN ICE

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LIFE TIME OF NONEQUILIBRIUM CHARGE CARRIERS IN ICE

NATURE OF PHOTO-CHARGE CARRIERS IN ICE

ELECTROMOTIVE FORCE

ELECTRO-OPTICAL EFFECTS AT ICE-SEMICONDUCTOR INTERFACES

POSSIBILITY OF ICE SOLAR CELLS

PHOTOPLASTIC EFFECT IN ICE

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